January 9st 2001

GM

Nominal Voltage distributions
of the three first batches of phototubes

1. Introduction

Data provided for each delivered tubes by Hamamatsu include:

- the photocathode sensibility, S_k, expressed in μA per lumen,
- the anode sensibility, measured at 800 Volts, S_a, expressed in A per lumen,

For each tube, we measure on the test-benches the current amplification curve, and from this curve, we deduce:

- the nominal voltage to get a current amplification of 10^5
- the β parameter characterizing the variation of the current amplification of each tube as a function of a variation of the applied voltage, and assuming that the current amplification could be fitted as:

$$G = \alpha V^{\beta}$$

When looking on the correlation between the nominal voltage provided by Hamamatsu and the nominal voltage extracted from ATLAS measurements, we got the following results:

- Figure (1) for batch #1 (CL1) with: $HV_{ATLAS} = 0.9159 \times HV_{Ham.} + 35.09$ (R^2=0.983)
- Figure (2) for batch #2 (CL2) with: $HV_{ATLAS} = 0.9216 \times HV_{Ham.} + 26.6$ (R^2=0.977)
- Figure (3) for batch #3 (Pisa) with: $HV_{ATLAS} = 0.9142 \times HV_{Ham.} + 35.854$ (R^2=0.982)
- Figure (4) for batch #3 (Urbana) with: $HV_{ATLAS} = 0.8984 \times HV_{Ham.} + 45.174$ (R^2=0.951)

Figures (5) to (7) show these correlation lines measures for each run of the batch #3 (Urbana). Comparing the different batches to a reference batch (batch #1), we can deduce:

- Batch #1 (CL1) and batch #2 (CL2) have quite the same slope but some systematic shift as shown on Figure (8). Using 700 Volts nominal voltage, the shift is:

  $$HV_1 = 0.9159 \times 700 + 35.09 = 676.22 \text{ Volts}$$

  $$HV_2 = 0.9216 \times 700 + 26.597 = 671.72 \text{ Volts}$$

  ΔHV = 4.5 Volts, and Figure(9) shows the result after this correction

- Batch #1 (CL1) and batch #3 (Pisa) agreement is very impressive has shown on Figure (10), since the regression lines are quite identical,
- Batch #1 (CL1) and batch #3 (Urbana) agreement is also very good has shown on Figure (11),

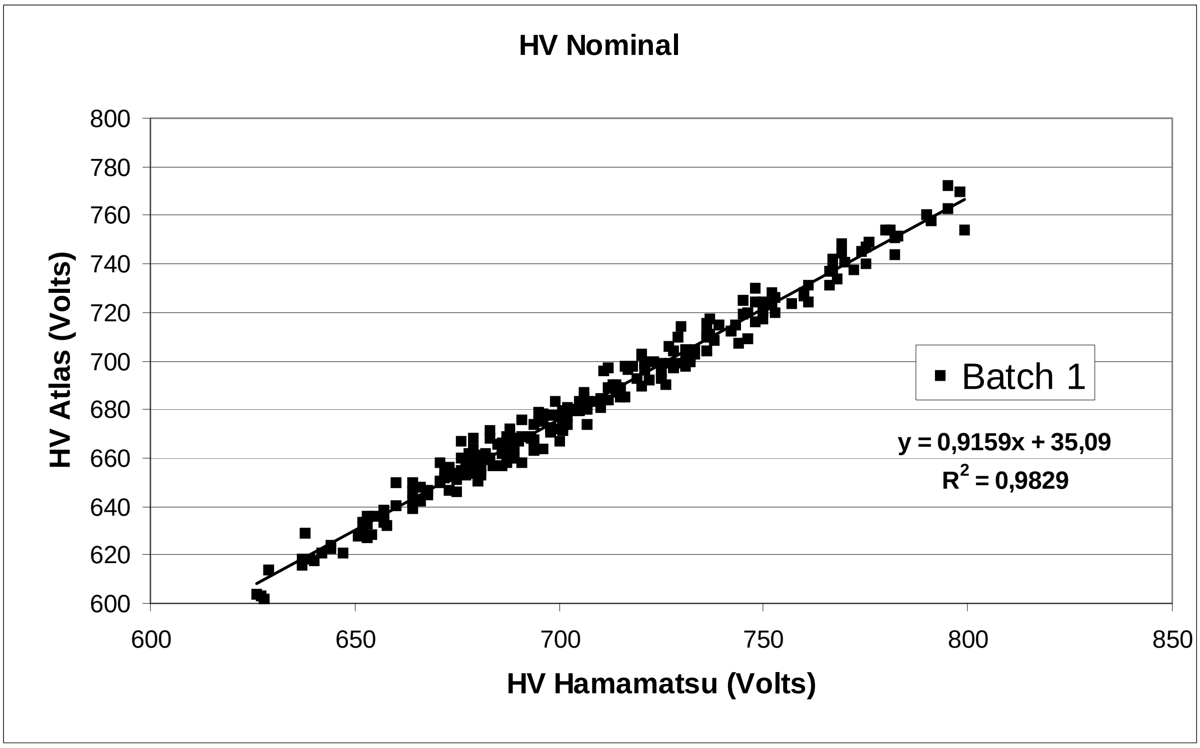

Figure (1) : Nominal voltage measured by ATLAS for batch #1 (CL1), as a function of the nominal voltage provided by Hamamatsu

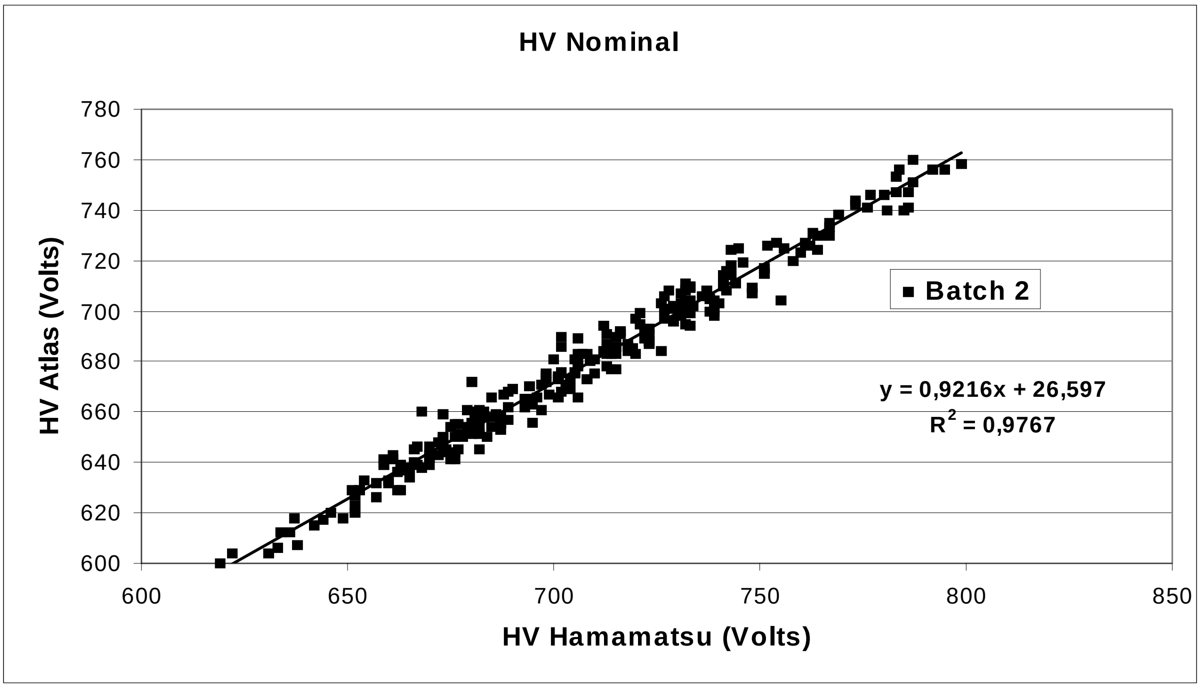

Figure (2) : Nominal voltage measured by ATLAS for batch #2 (CL2), as a function of the nominal voltage provided by Hamamatsu

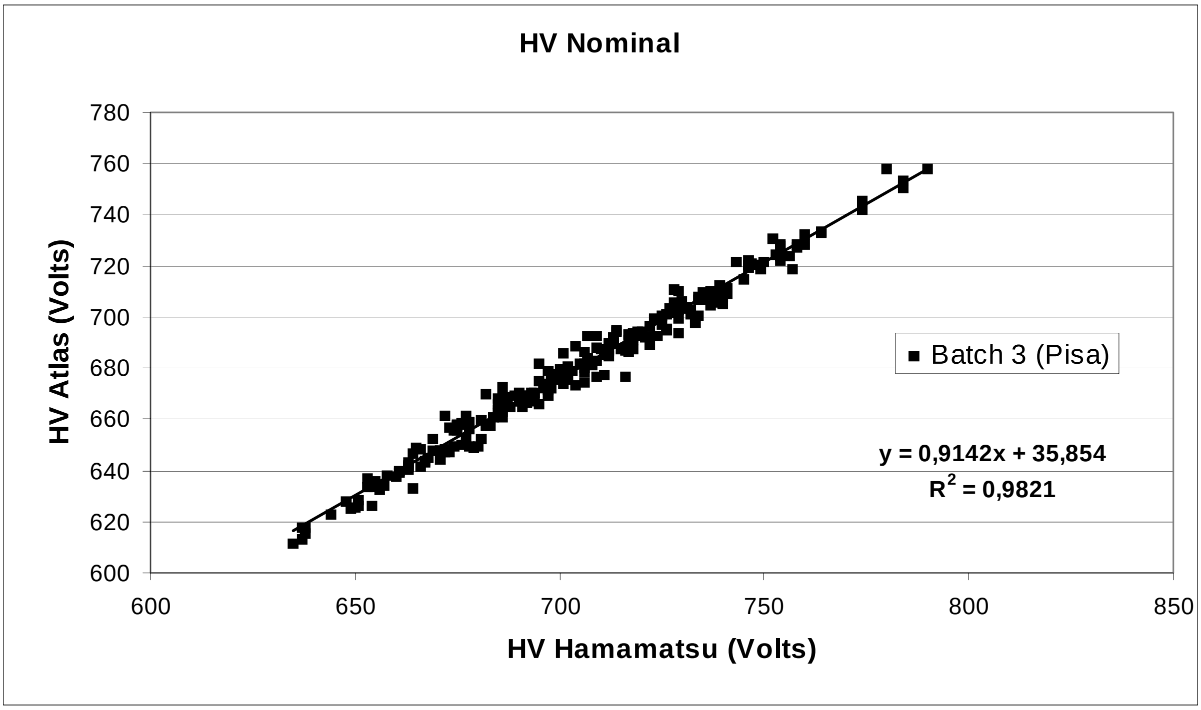

Figure (3) : Nominal voltage measured by ATLAS for batch #3 (Pisa), as a function of the nominal voltage provided by Hamamatsu

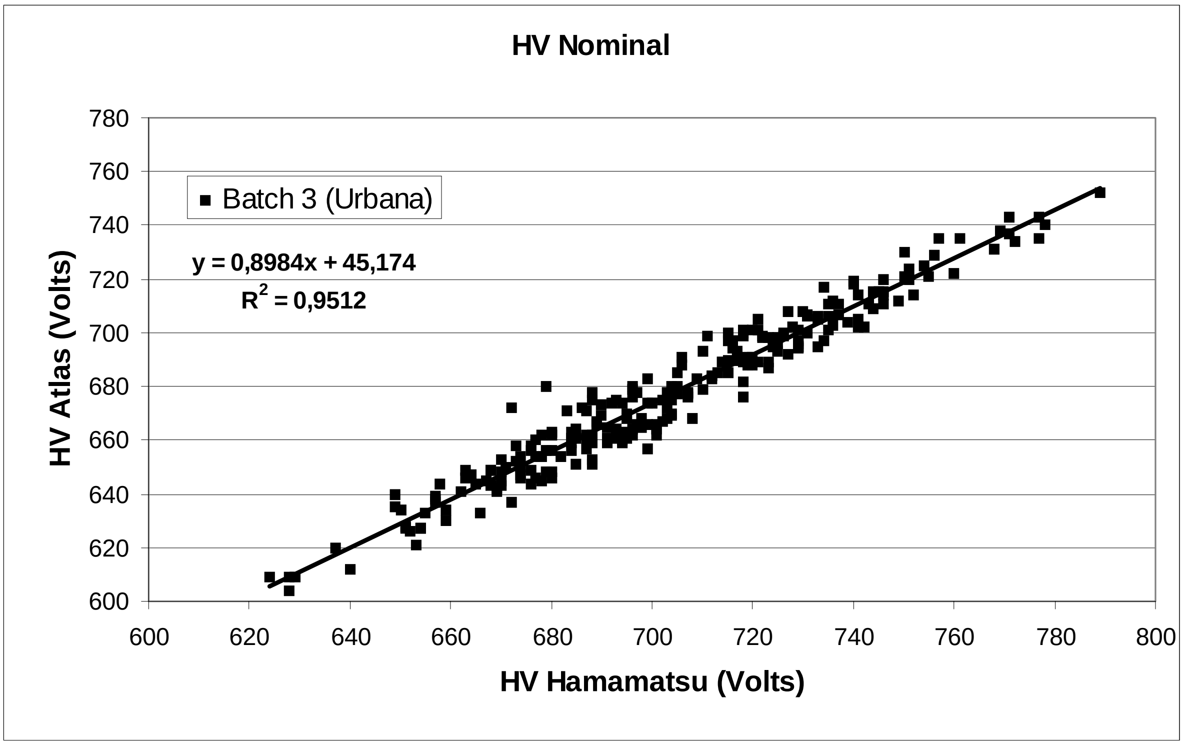

Figure (4) : Nominal voltage measured by ATLAS for batch #3 (Urbana), as a function of the nominal voltage provided by Hamamatsu

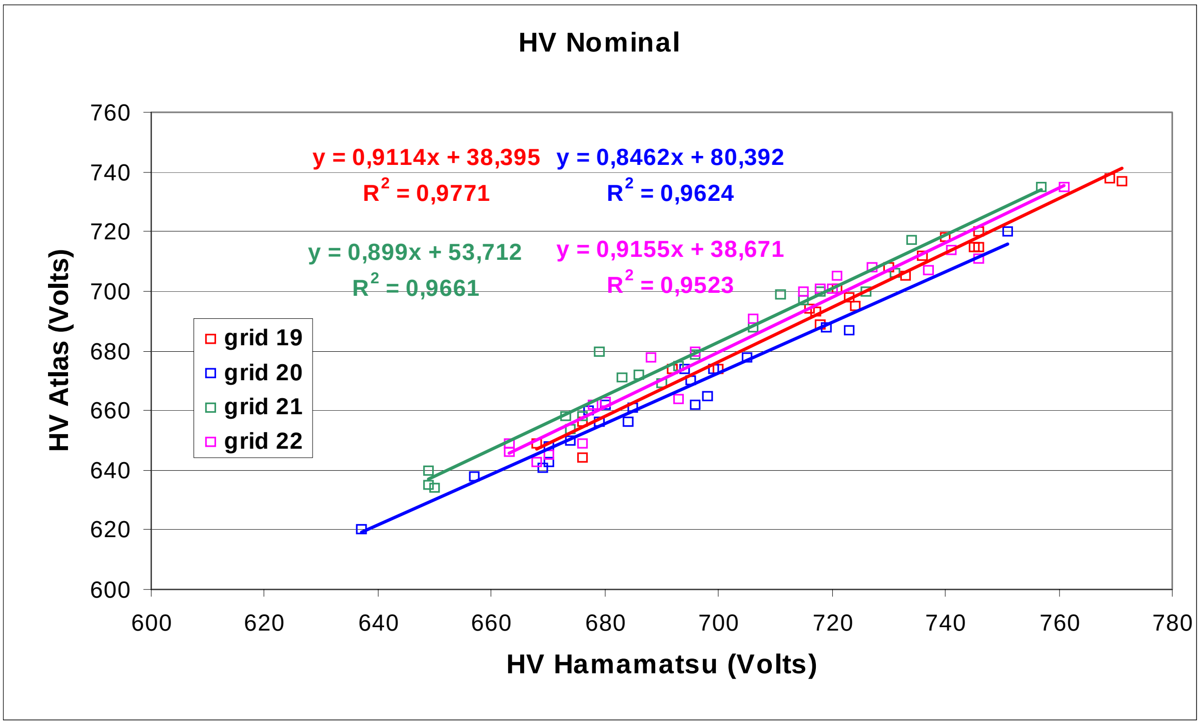

Figure (5) : Nominal voltage measured by ATLAS for batch #3 (Urbana), as a function of this nominal voltage provided by Hamamatsu. The correlation is measured for each run separately (run #19 to #22)

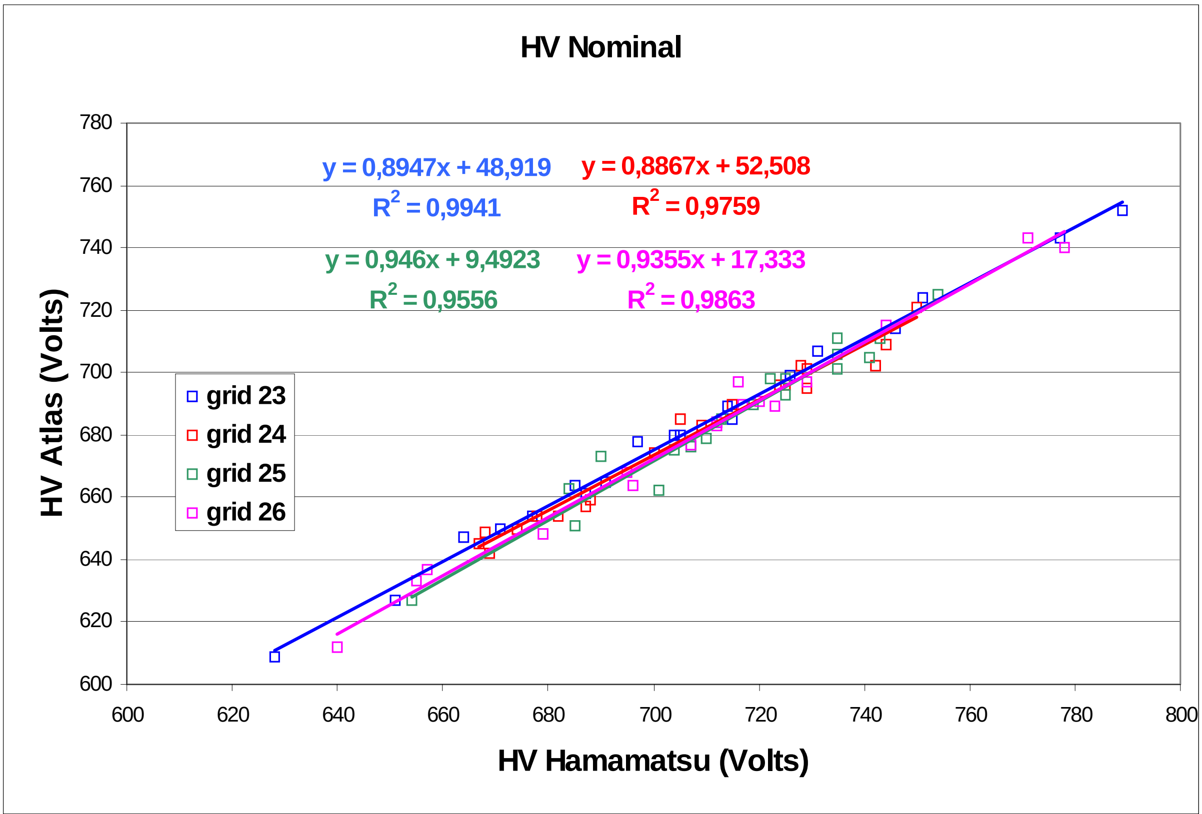

Figure (6) : Nominal voltage measured by ATLAS for batch #3 (Urbana), as a function of this nominal voltage provided by Hamamatsu. The correlation is measured for each run separately (run #23 to #26)

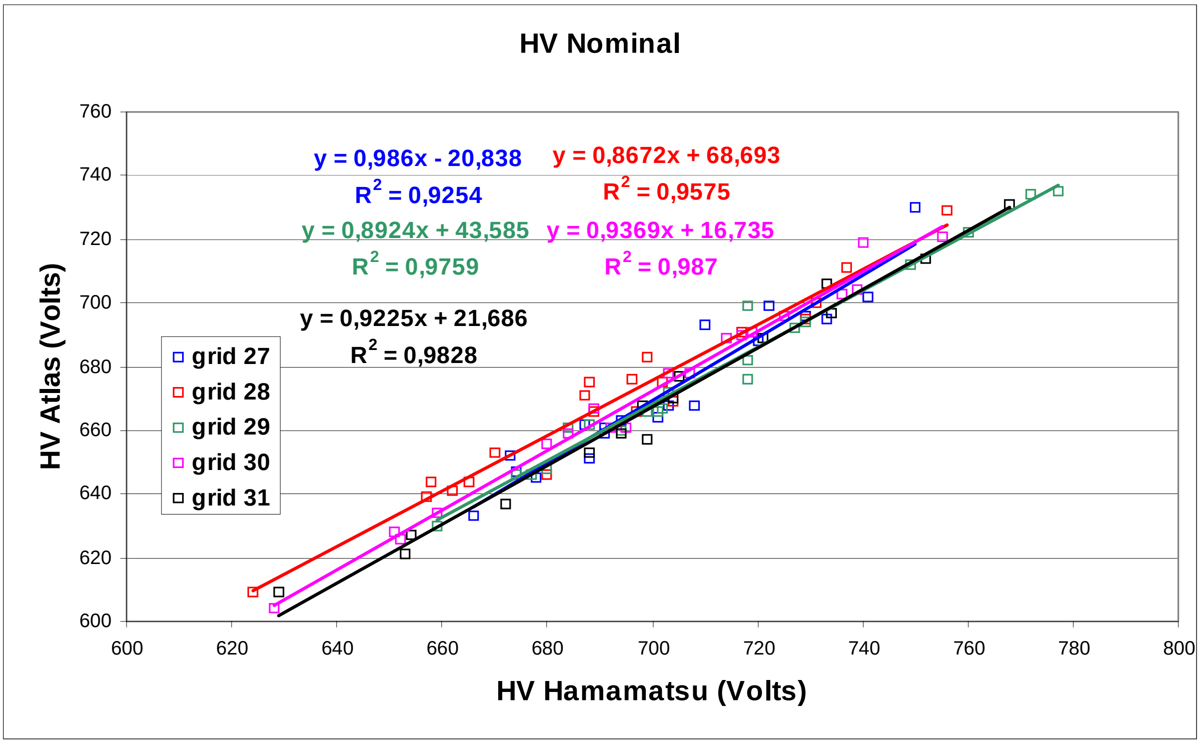

Figure (7) : Nominal voltage measured by ATLAS for batch #3 (Urbana), as a function of this nominal voltage provided by Hamamatsu. The correlation is measured for each run separately (run #27 to #31)

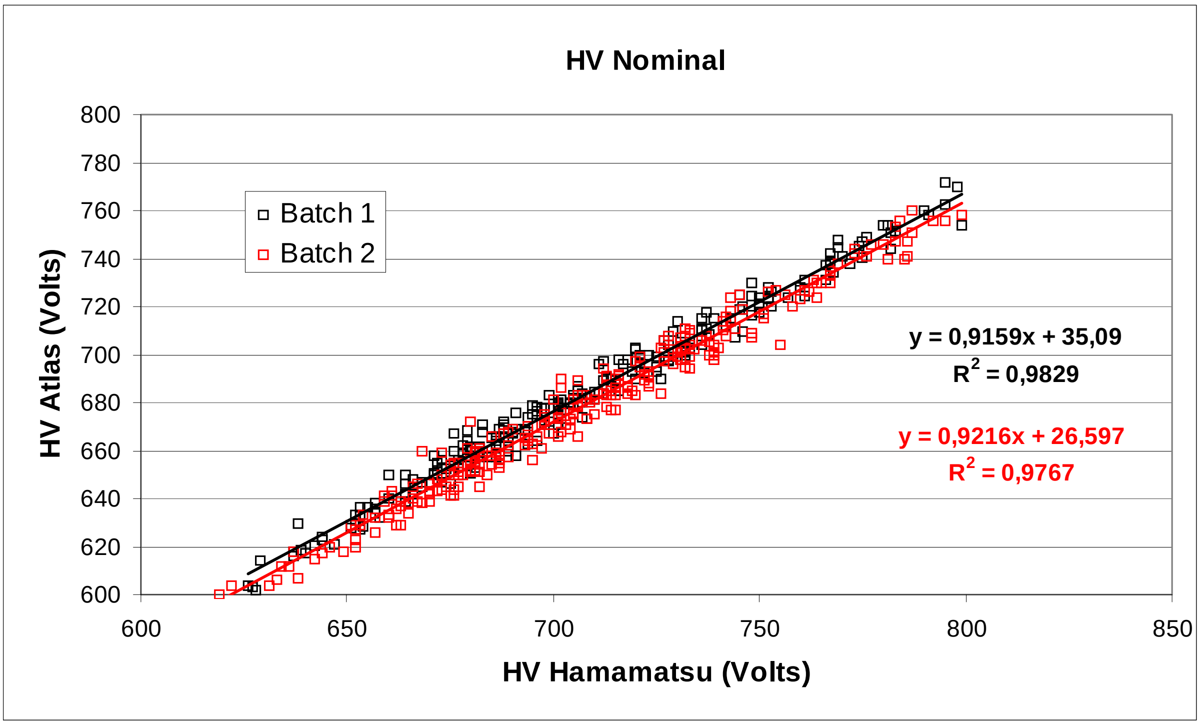

Figure (8) : Comparison of the correlations between the nominal voltage measured by ATLAS and the nominal voltage provided by Hamamatsu, for batch #1 and batch #2

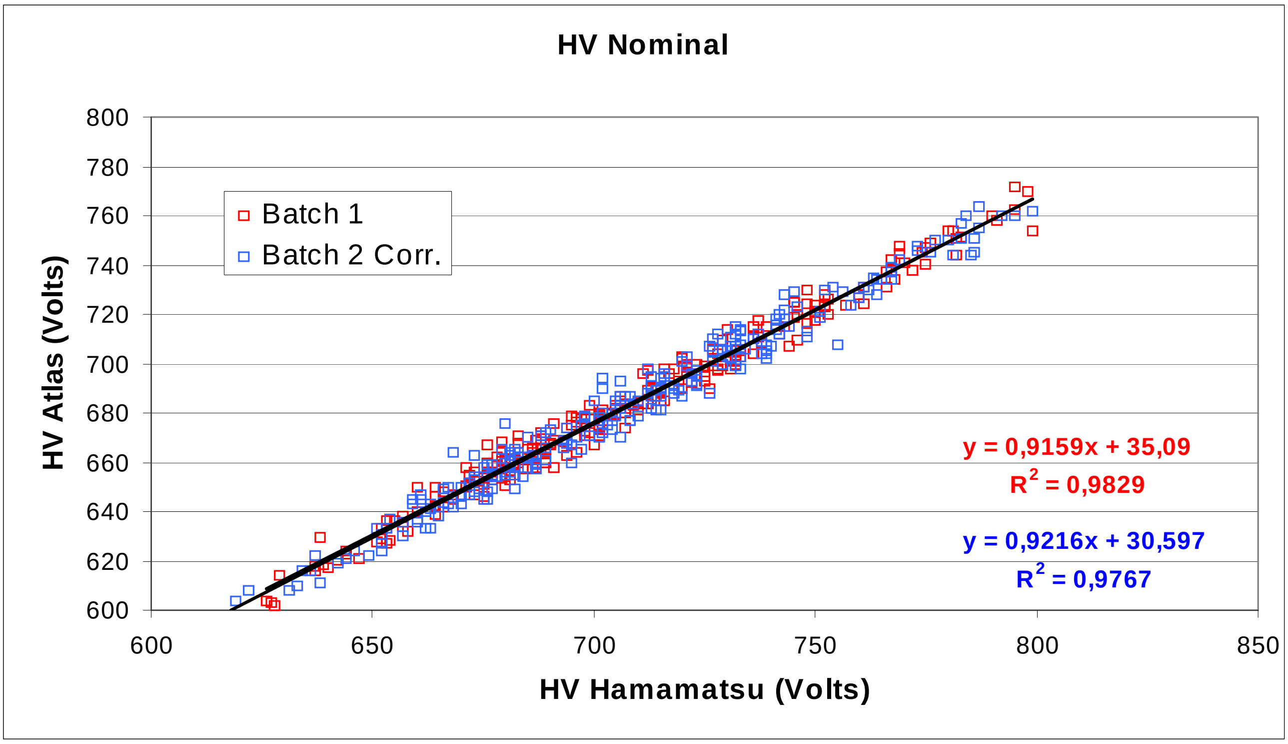

Figure (9) : Comparison of the correlations between the nominal voltage measured by ATLAS and the nominal voltage provided by Hamamatsu for batch #1 and batch #2. A systematic correction of 4.5 Volts had been applied to batch #2

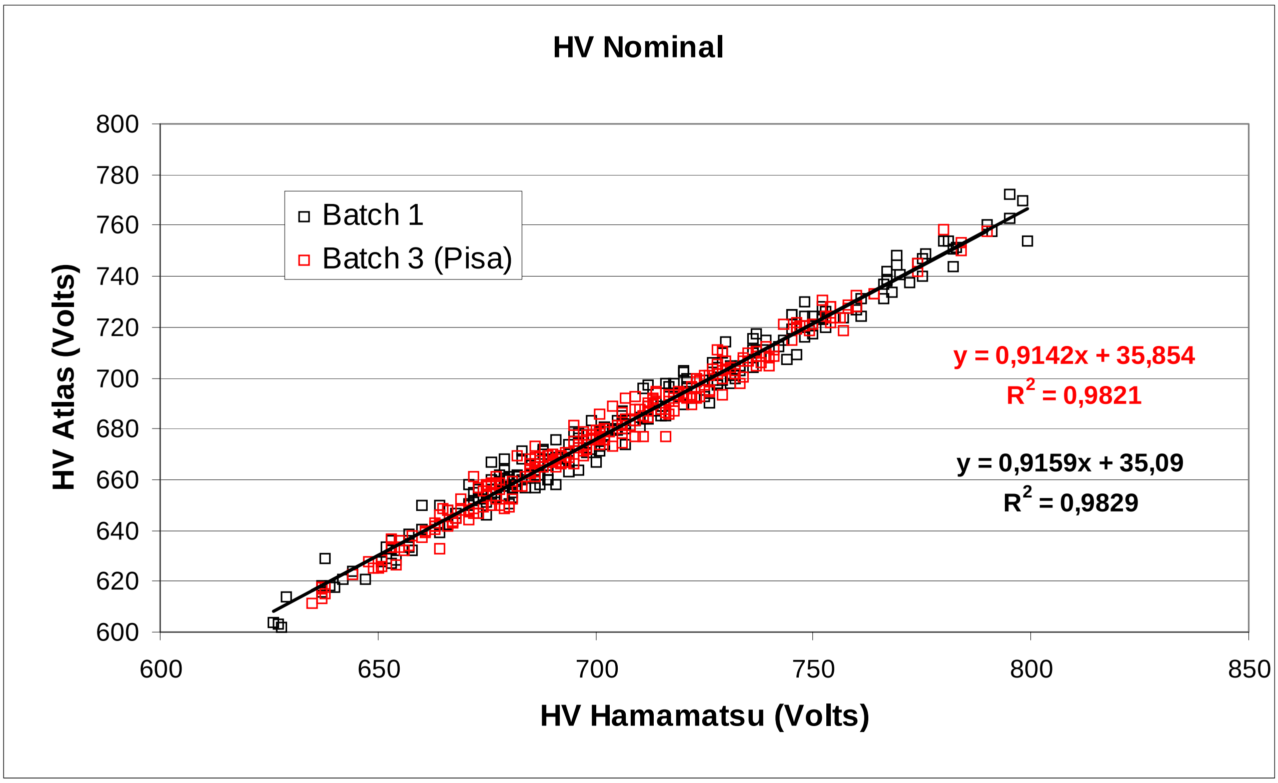

Figure (10) : Comparison of the correlations between the nominal voltage measured by ATLAS and the nominal voltage provided by Hamamatsu for batch #1 and batch #3 (Pisa).

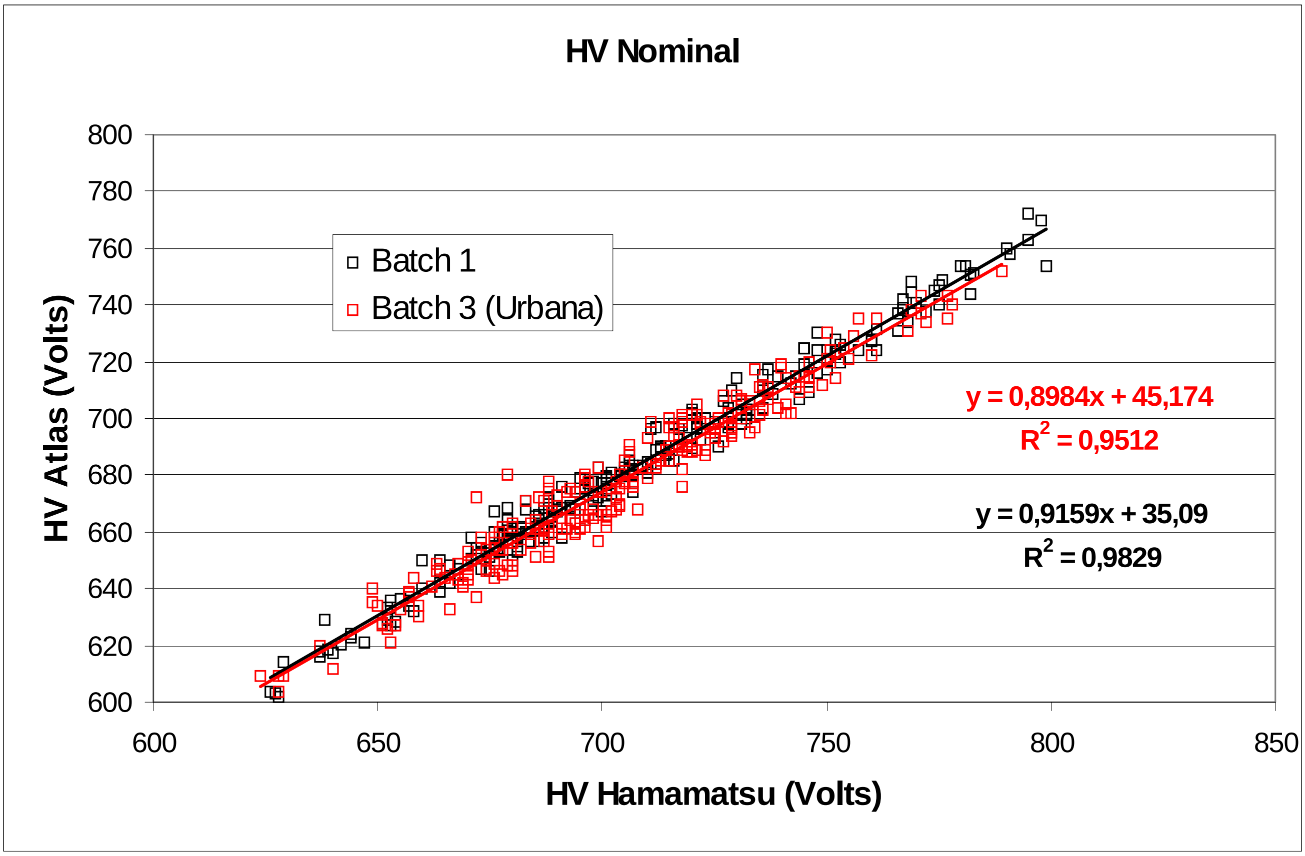

Figure (11) : Comparison of the correlations between the nominal voltage measured by ATLAS and the nominal voltage provided by Hamamatsu for batch #1 and batch #3 (Urbana)

We also look on the measurements of the nominal voltage of the subset of 24 tubes that makes the intercalibration grid. The results for the different test-benches are shown on Figure (12) with different colours:

- Original measurement on CL test-bench (black symbols),
- First measurement on Pisa test-bench (red symbols),
- First measurement on Valencia test-bench (blue symbols),
- First measurement on Urbana test-bench (green symbols),
- Second measurement on Urbana test-bench (purple symbols),

Precise comparisons are quite difficult since only 24 tubes are used to get each correlation lines. But we can nevertheless conclude that all the correlation lines have the same slope. Moreover except Urbana 2, all these correlation lines are rather identical. Stability of the monitoring PMTs is also good:

- Figure (13) shows variation of the 4 PMTs (AA1328, AA1354, AA1390 and AA1407) over all runs of batch #3 for Urbana test-bench. Maximum variation is less than 1%.

- Figure (14) shows variation of the 4 PMTs (AA613, AA615, AA617 and AA619) over all runs of batch #2 for Clermont test-bench. Maximum variation is worse but less than 2%.

- Data for other test-benches are not yet available,

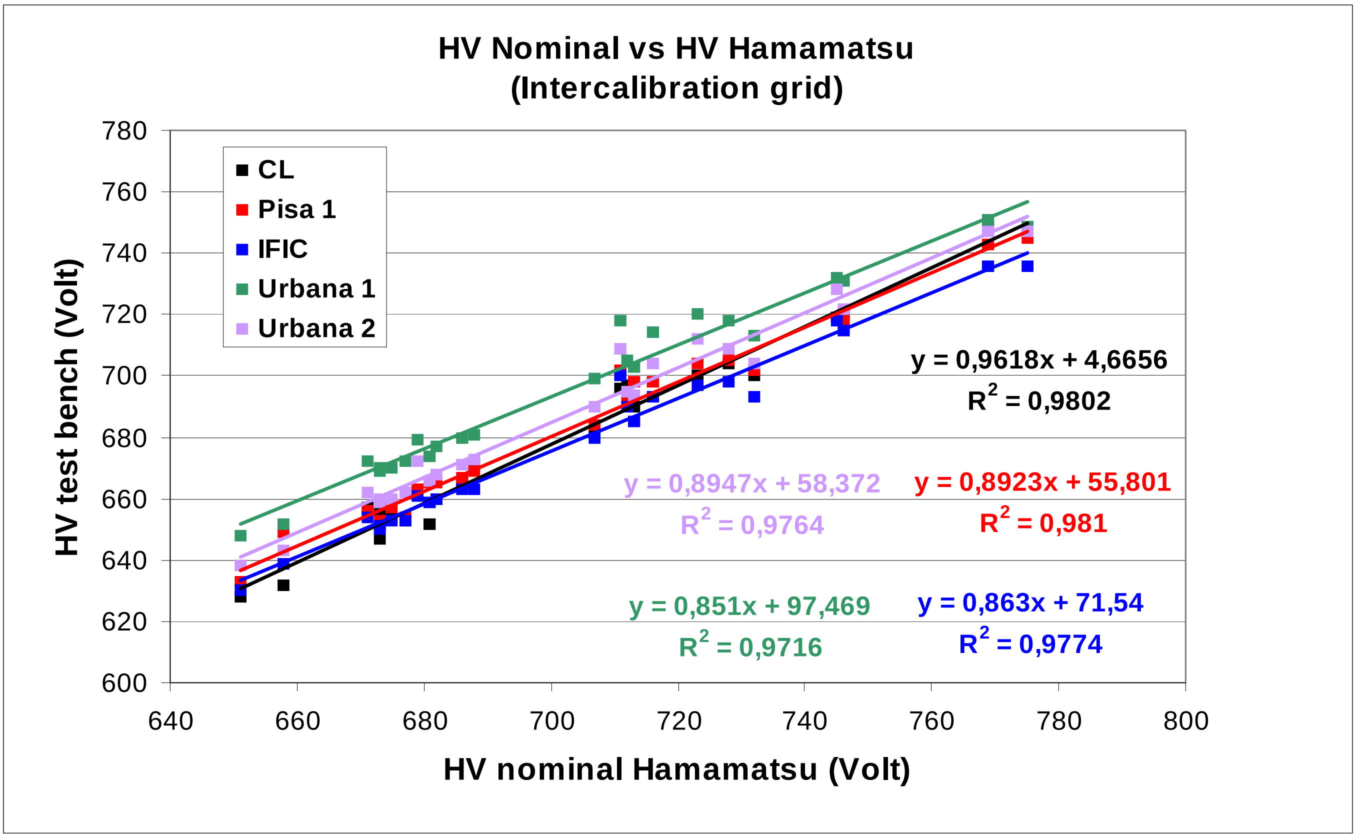

Figure (12) : Correlation between the nominal voltage provided by Hamamatsu and measured by ATLAS for the subset of 24 tubes that makes the intercalibration grid. The results for the different test-benches are shown with different colours.

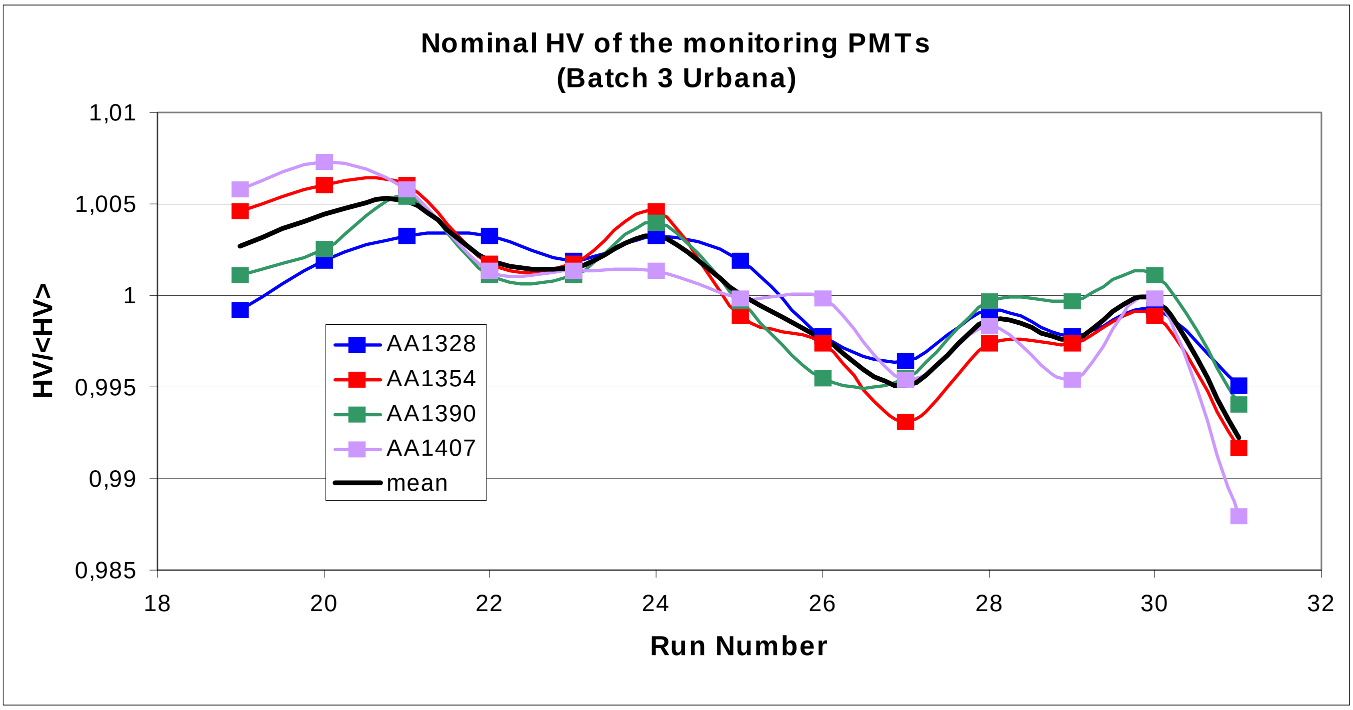

Figure (13) : Variation of the nominal voltage of the 4 monitoring PMTs (AA1328, AA1354, AA1390 and AA1407) over all runs of batch #3 for Urbana test-bench. Maximum variation is less than 1%.

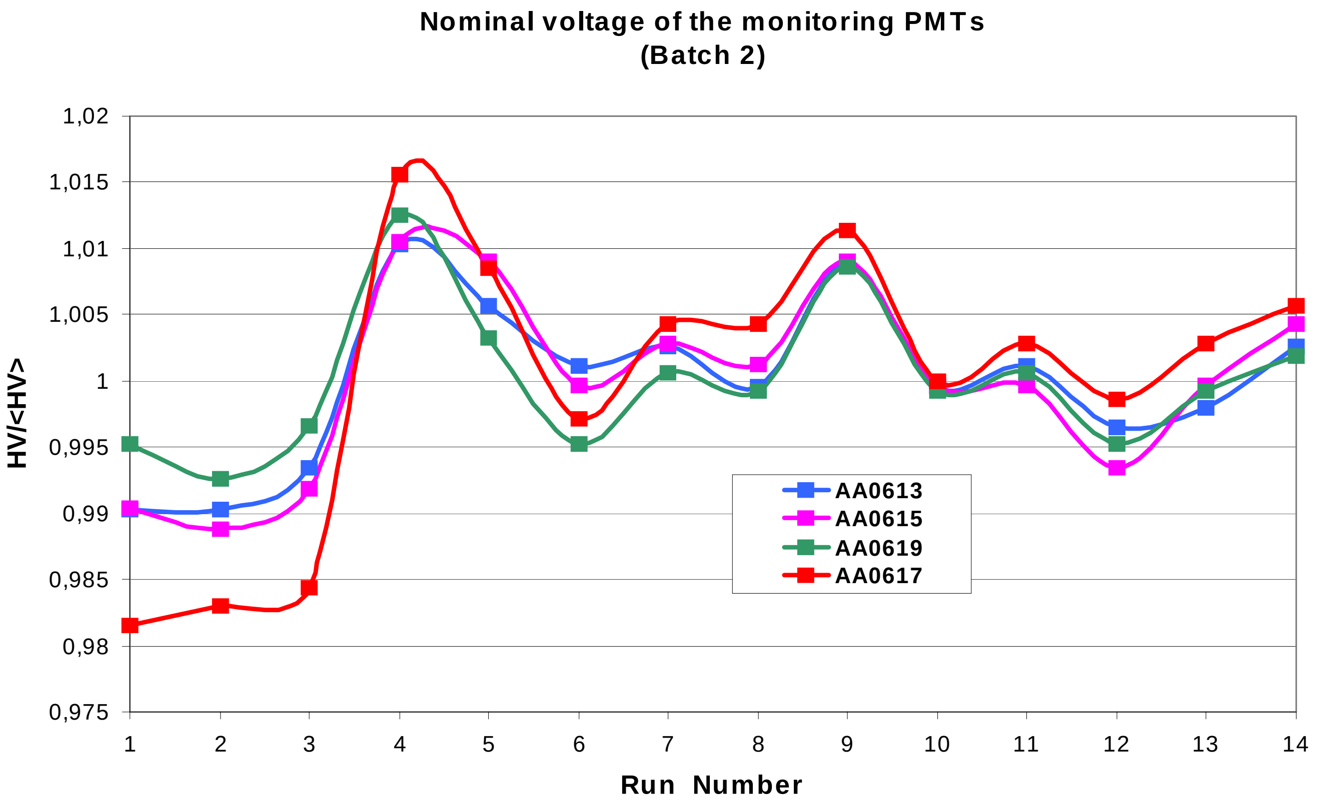

Figure (14) : Variation of the nominal voltage of the 4 monitoring PMTs (AA613, AA615, AA617 and AA619) over all runs of batch #2 for CL test-bench. Maximum variation is less than 2%.

Using results of this stability plots, we try to correct the measured nominal voltage of some runs, when the shift from the averaged value is significative.
Such a correction is not useful since as shown on Figure (15) for batch #3 (Urbana) and Figure (16) for batch #2, it does not improve so much the correlation figures.

2. Estimation of β

Using the Hamamatsu provided data, we try to extract the quality and compatibility of the 1000 tubes out of the 1250 first delivered tubes.
We assume, that the amplification curve of each tubes could be fitted, in first approximation, with the following equation:

$$G = \alpha V^{\beta}$$

So

$$G_{Nom} = 10^5 \alpha HV_{Nom}^{\beta}$$

Moreover the ratio of S_A and S_K, measured at some voltage (800 Volts) correspond to the current amplification at this voltage:

$$10^6 S_A / S_K = G(V=800 \text{ Volts})$$

The 10^6 factor correspond to the conversion from A/lumen to μA/lumen.

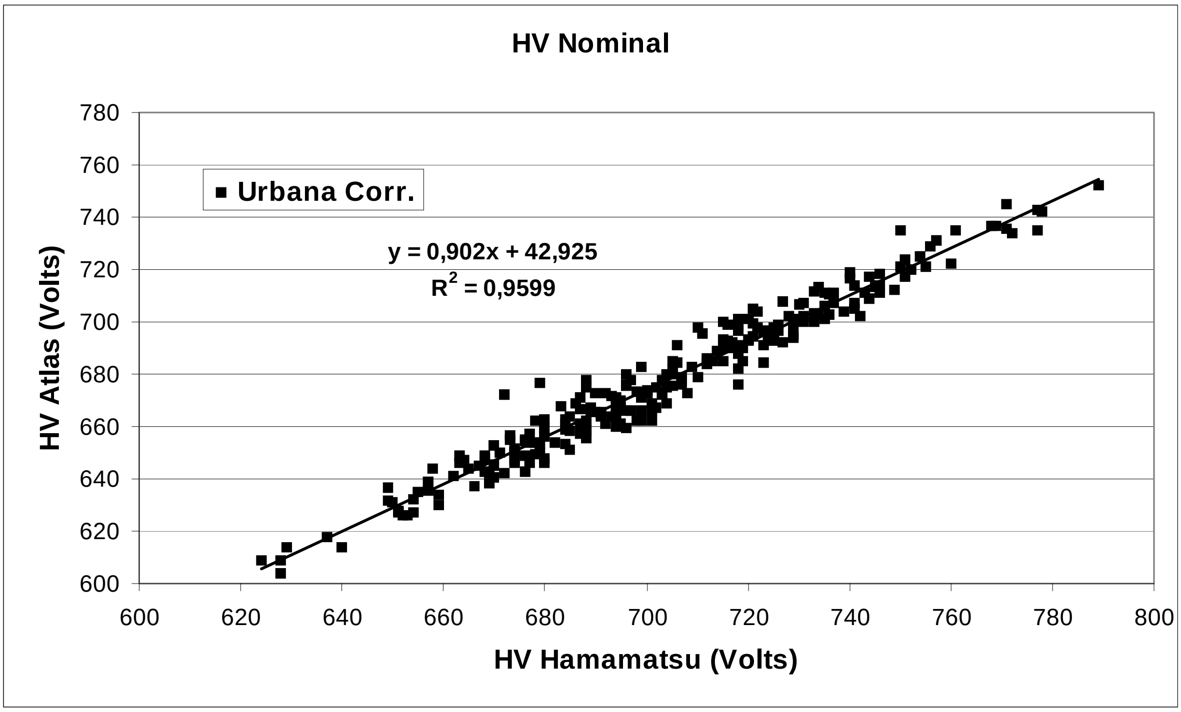

Figure (15) : Nominal voltage measured by ATLAS for batch #3 (Urbana), as a function of this nominal voltage provided by Hamamatsu. ATLAS measured nominal voltages have been corrected, for some run, using results of monitoring PMTS when their variation from the mean is significative (Figure(13)). This plot should be compared to the one shown in Figure(1)

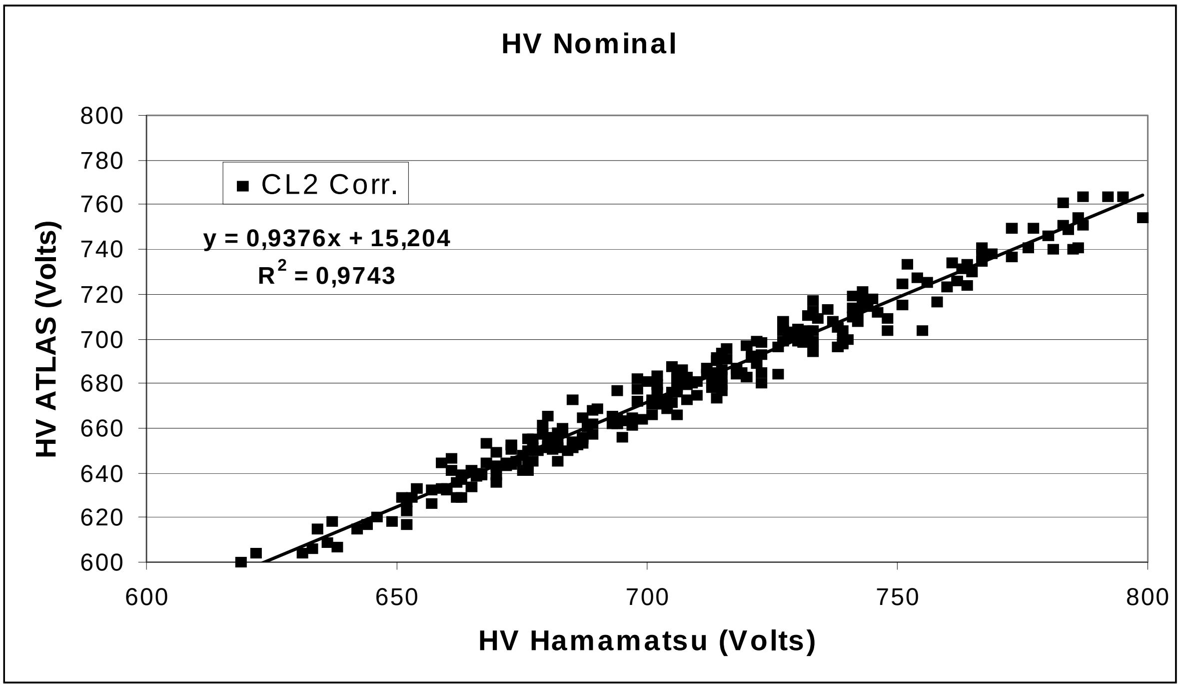

Figure (16) : Nominal voltage measured by ATLAS for batch #2, as a function of this nominal voltage provided by Hamamatsu. ATLAS measured nominal voltages have been corrected, for some run, using results of monitoring PMTS when their variation from the mean is significative(Figure(14)). This plot should be compared to the one shown on Figure (2)

From these equations, we could extract:

$$(10^6 / 10^5) \times (S_A / S_K) = (\alpha V^{\beta}) \times (\alpha HV_{Nom.}{}^{\beta}) = (V / HV_{Nom.})^{\beta} = (800 / HV_{Nom.})^{\beta}$$

$$10 \times (S_A / S_K) = (800 / HV_{Nom.})^{\beta}$$

$$Log_{10} (S_A / S_K) + 1 = \beta \, Log_{10} (800) - \beta \, Log_{10} (HV_{Nom})$$

$$Log_{10} (HV_{Nom}) = - (1 / \beta) \, Log_{10} (S_A / S_K) + Log_{10} (800) – (1 / \beta)$$

So plotting the correlation $Log_{10} (HV_{Nom})$ versus $Log_{10} (S_A / S_K)$ for a batch, we get some correlation line with the slope equal to ~ 1 / <β>.

Figure (17) shows the exercise for PMTs of batch #1:

$$1 / < \beta > = 0{,}14 \Rightarrow < \beta > = 7.117$$

The constant term is Log_{10} (800) – (1 / β) equal to 2.9031 – 0.14 = 2.763 for an estimed value of 2.762

Something different appears on Figure (18) and (19) that represent the results for the batch #2 and batch #3 (Pisa). For each of these batches, there are two different set of PMTs, and so two different correlation lines with nevertheless the same slope and so the same <β> for each batch.

Batch #2 (CL2) :

Subset #1 ➔ $Log_{10} (HV_{Nom}) = -0.1356 \; Log_{10} (S_A / S_K) + 2.7782$

Subset #2 ➔ $Log_{10} (HV_{Nom}) = -0.1403 \; Log_{10} (S_A / S_K) + 2.7617$

Batch #3 (Pisa) :

Subset #1 ➔ $Log_{10} (HV_{Nom}) = -0.1393 \; Log_{10} (S_A / S_K) + 2.7616$

Subset #2 ➔ $Log_{10} (HV_{Nom}) = -0.1394 \; Log_{10} (S_A / S_K) + 2.7756$

Batch #3 (Urbana) is homogeneous with only 4 tubes which seems different as shown on Figure (20)

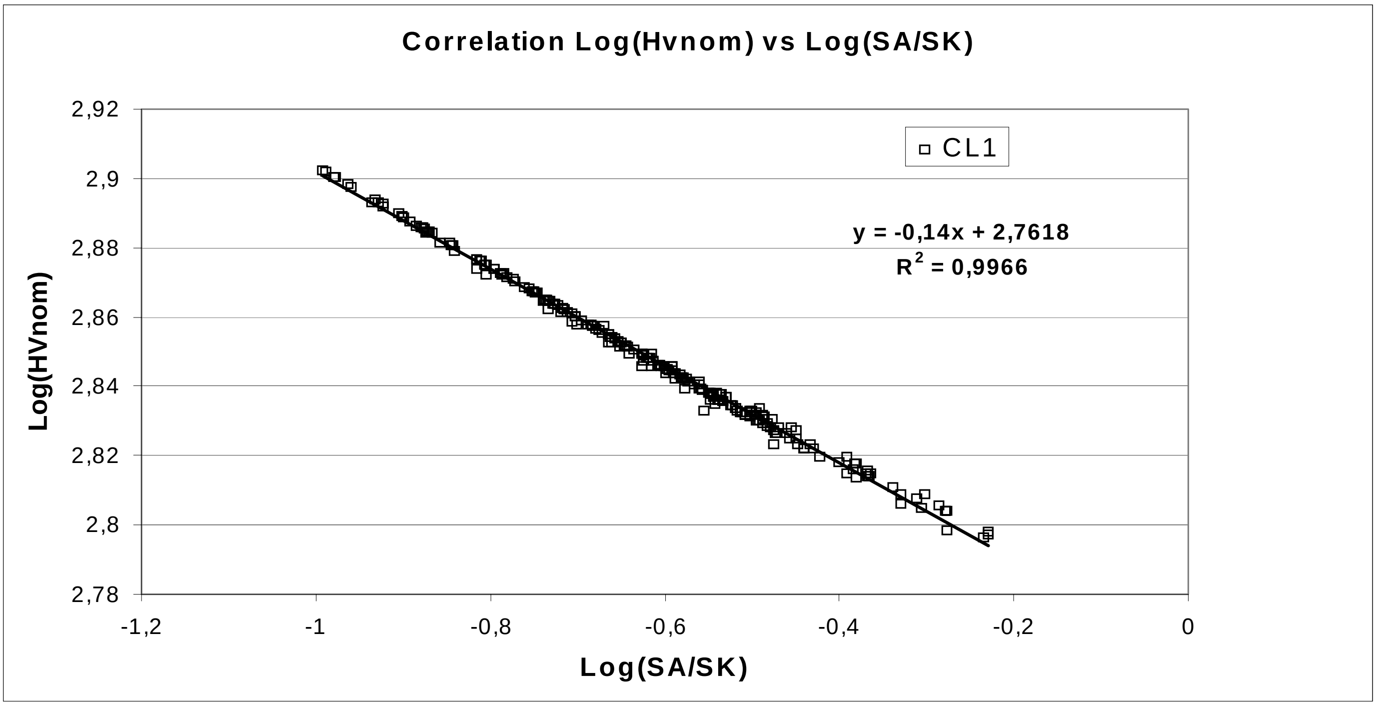

Figure (17) : Correlation Log_{10} (HV_{Nom}) versus Log_{10} (S_A / S_K) for the PMTs of the batch #1, using data provided by Hamamatsu. The slope is equal to – 1 / <β>

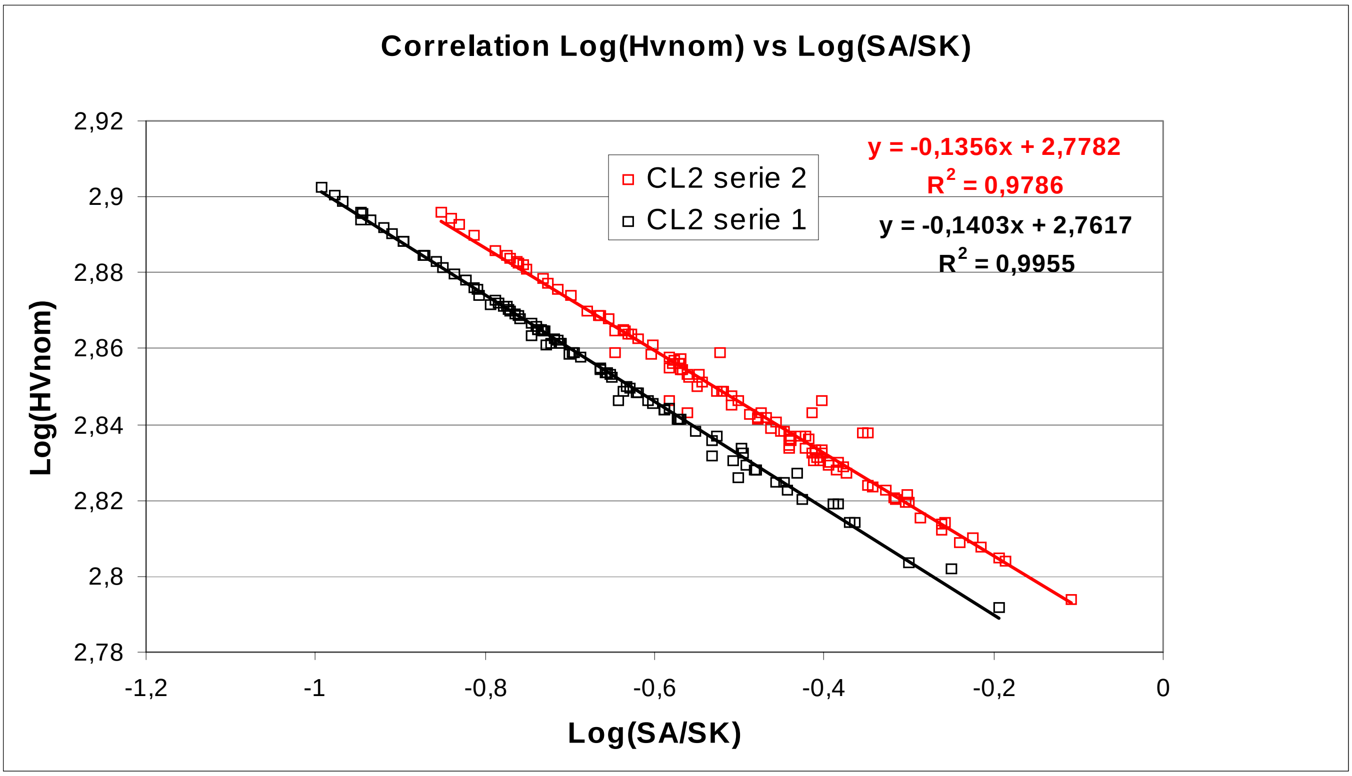

Figure (18) : Correlation Log_{10} (HV_{Nom}) versus Log_{10} (S_A / S_K) for the PMTs of the batch #2, using data provided by Hamamatsu. The slope is equal to – 1 / <β>. Two different correlation lines appear, corresponding to two different subsets of PMTs. Nevertheless the slopes and so <β> are almost identical.

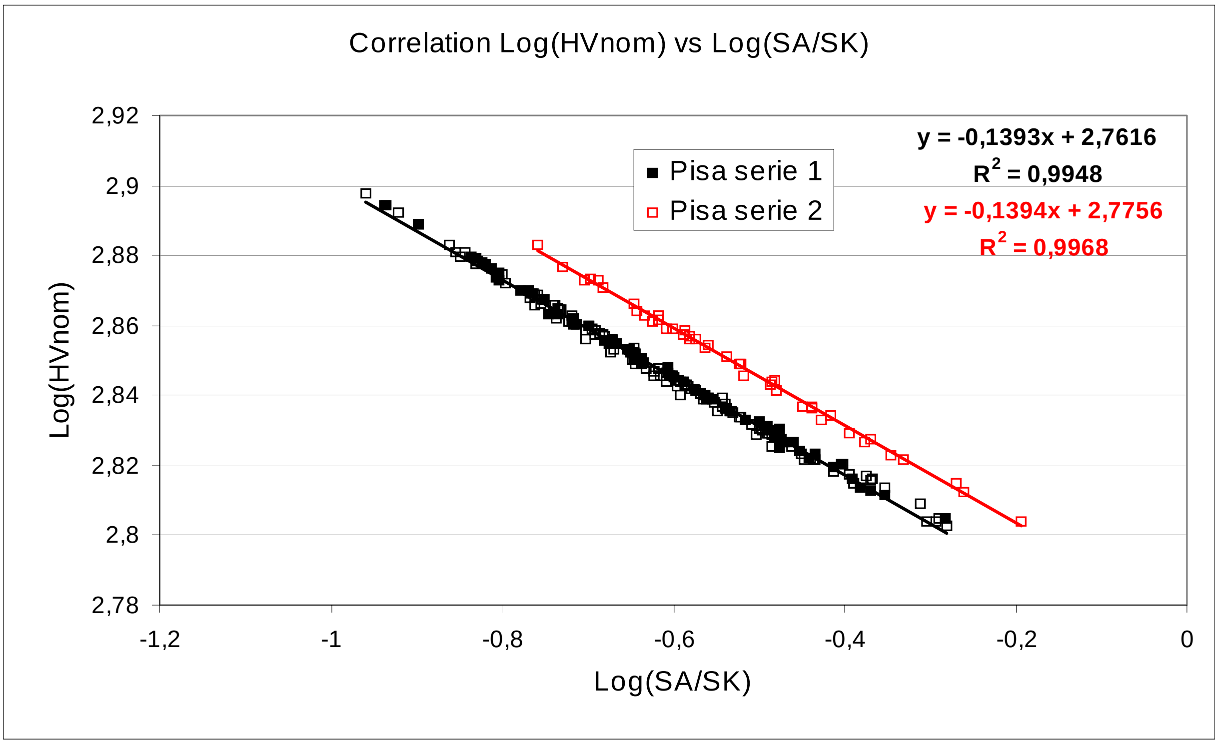

Figure (19) : Correlation Log_{10} (HV_{Nom}) versus Log_{10} (S_A / S_K) for the PMTs of the batch #3 (Pisa), using data provided by Hamamatsu. The slope is equal to – 1 / <β>. Two different correlation lines appear, corresponding to two different subset of PMTs. Nevertheless the slopes and so <β> are almost identical

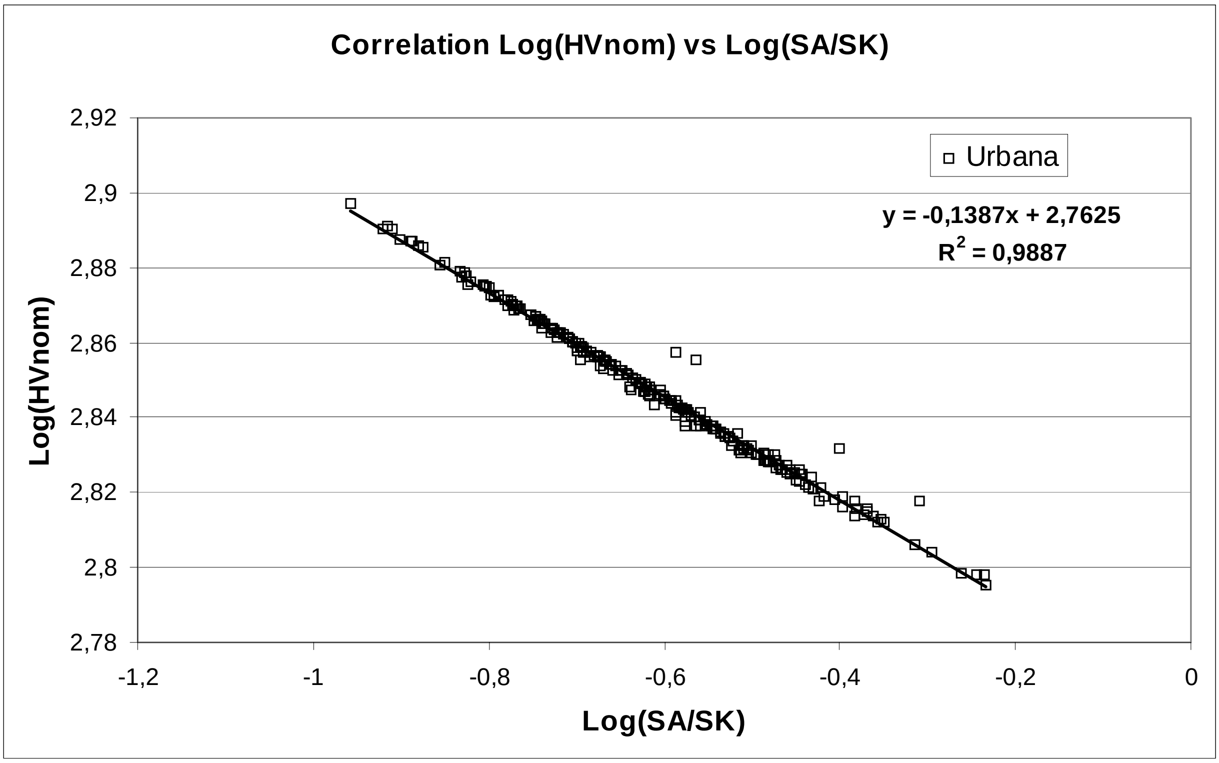

Figure (20) : Correlation Log_{10} (HV_{Nom}) versus Log_{10} (S_A / S_K) for the PMTs of the batch #3 (Urbana), using data provided by Hamamatsu. The slope is equal to – / <β>. Four PMTs seems to have different characteristics.

Assuming Hamamatsu don't measure S_A at 800 Volts but some different value V:

$$Log_{10}(HV_{Nom}) = -(1/\beta)\ Log_{10}(S_A / S_K) + Log_{10}(V) - (1/\beta)$$
$$Log_{10}(HV_{Nom}) = -(1/\beta)\ Log_{10}(S_A / S_K) + Log_{10}(K \times 800) - (1/\beta)$$

$$Log_{10}(HV_{Nom}) = -(1/\beta)\ Log_{10}(S_A / S_K) + Log_{10}(K) + Log_{10}(800) - (1/\beta)$$

$$Log_{10}(HV_{Nom}) = a_1 \times Log_{10}(S_A / S_K) + b_1 = a_2 \times Log_{10}(S_A / S_K) + b_2 + Log_{10}(K)$$

So difference of the constant term of the two subsets of PMTs is equal to Log_{10} (K).

- For batch #2 we calculate V ~ 830 Volts,
- For batch #3 (Pisa) we calculate V ~ 826 Volts,

On Figure (21) is shown the value of the voltage V as a function of the PMT serial number.

For each PMTs:

$$Log_{10}(HV_{Nom}) = -(1/\beta)\ Log_{10}(S_A / S_K) + Log_{10}(V) - (1/\beta)$$

and so

$$\beta = (Log_{10}(S_A / S_K) + 1) / Log_{10}(HV_{Nom} / V)$$

Figure (22) shows the estimed β value, using this method from the Hamamatsu data, as a function of the PMT serial number. For batch #2 (CL2) and batch #3 (Pisa), the value of V used to get the value of β is depending of the subset of the batch to which the PMT belongs.

The distribution of the estimed β presents some discontinuity, that comes from the fact that the $G = \alpha V^{\beta}$ does not fit exactly the current amplification curve

This is obvious on Figures (23) to (26) that show the correlation $10 \times S_A / S_K$ as a function of $X = (V/ HV_{Nom.})$

- for CL1 the fit get $0,9833\ X^{7,1171}$ instead of X^{β}
- for CL2 the fit get $0,979\ X^{7,1548}$ instead of X^{β}
- for batch #3 (Pisa) the fit get $0,9736\ X^{7,125}$ instead of X^{β}
- for batch #3 (Urbana) the fit get $0,9776\ X^{7,1053}$ instead of X^{β}

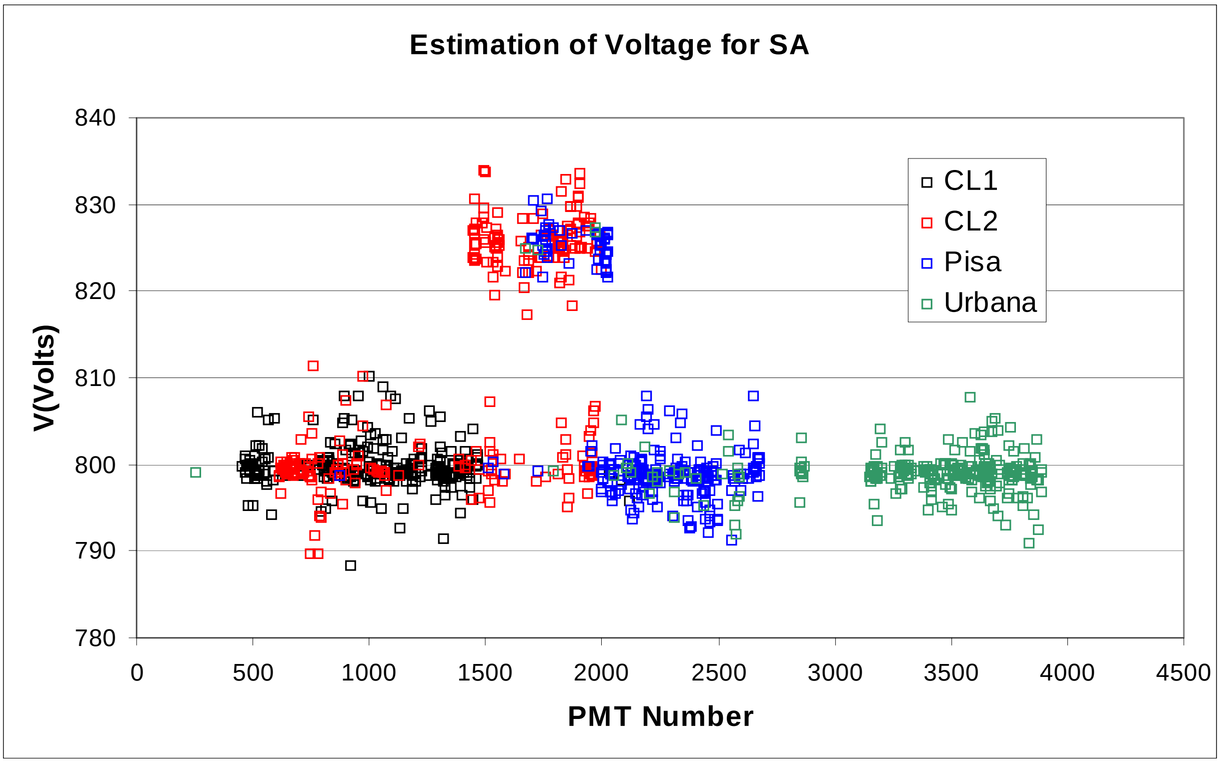

Figure (21) : Value of the voltage V, used by Hamamatsu, to measure S_A, as a function of the PMT serial number.

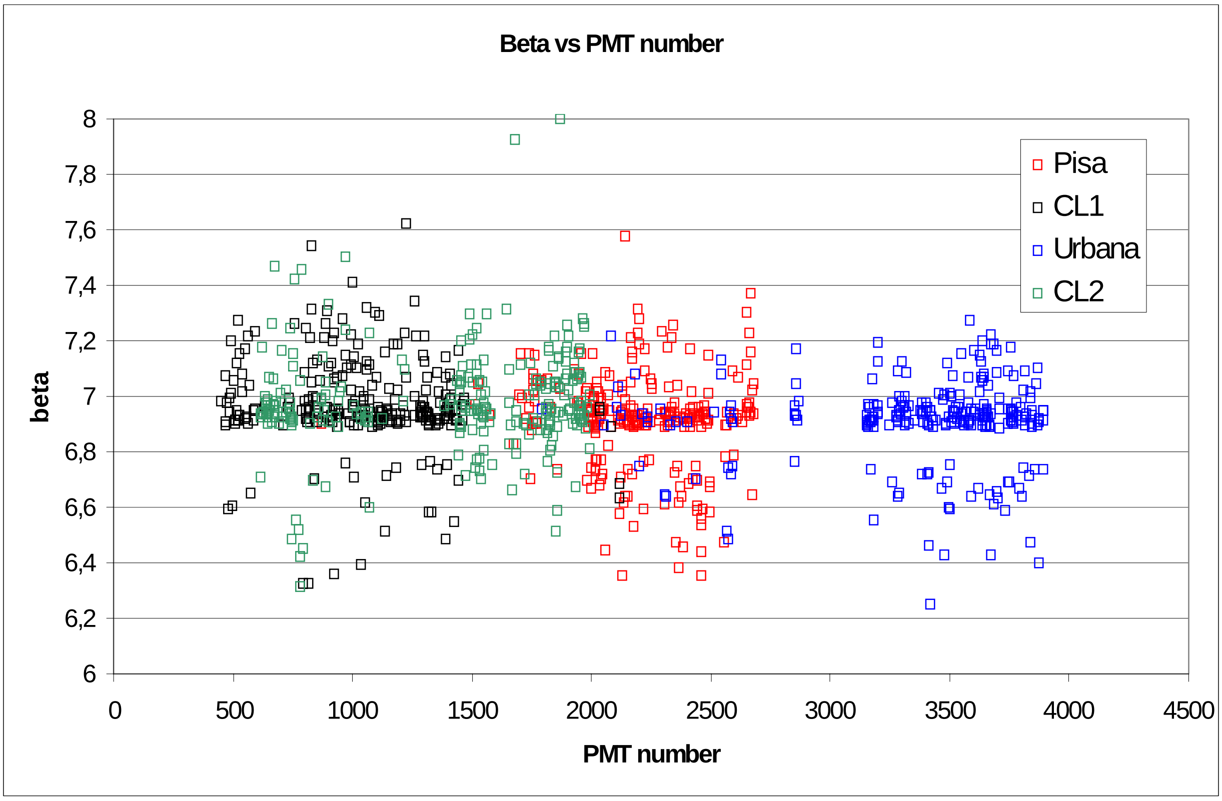

Figure (22) : Estimed β value, from $\beta = (Log_{10} (S_A / S_K) + 1) / Log_{10} (HV_{Nom} / V)$ using Hamamatsu data, as a function of the PMT serial number. For batch #2 (CL2) and batch #3 (Pisa), the value of V used to get the value of β is depending of the subset of the batch to which the PMT belongs.

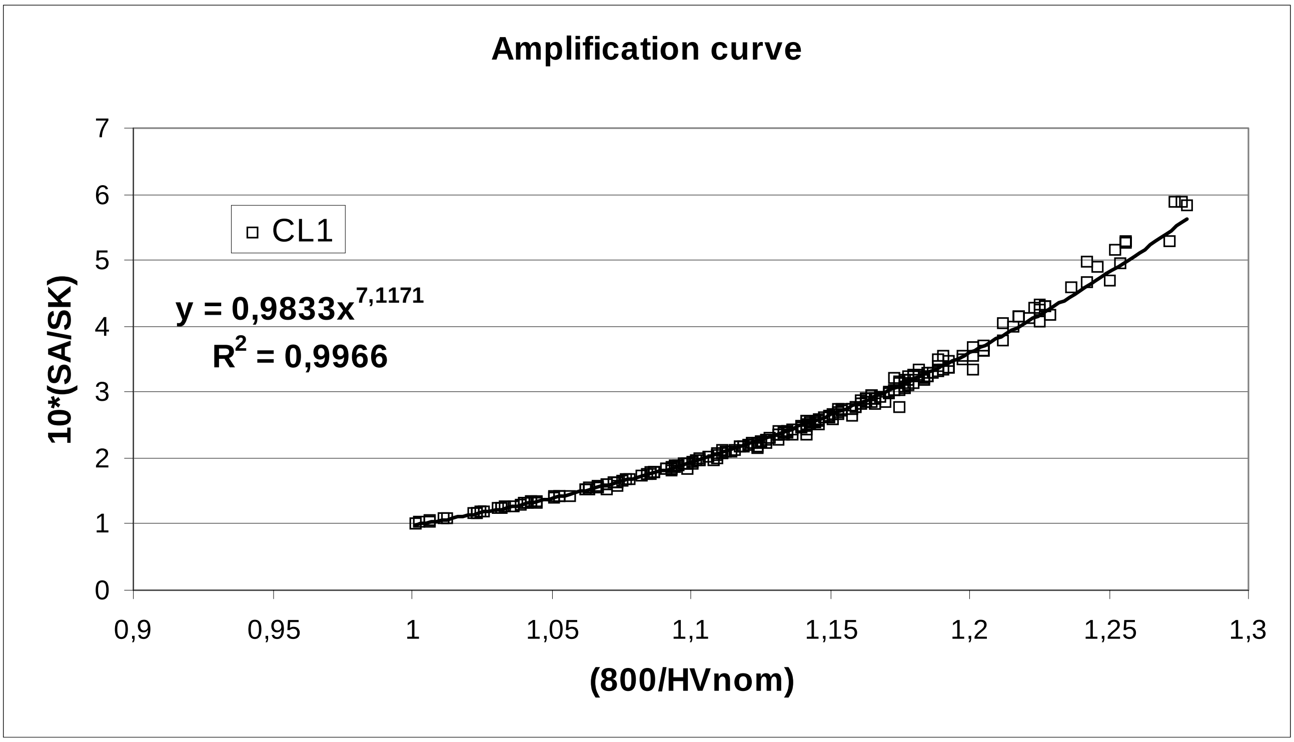

Figure (22) : Correlation 10 x S_A / S_K as a function of X = (V/ $HV_{Nom.}$) for batch #1

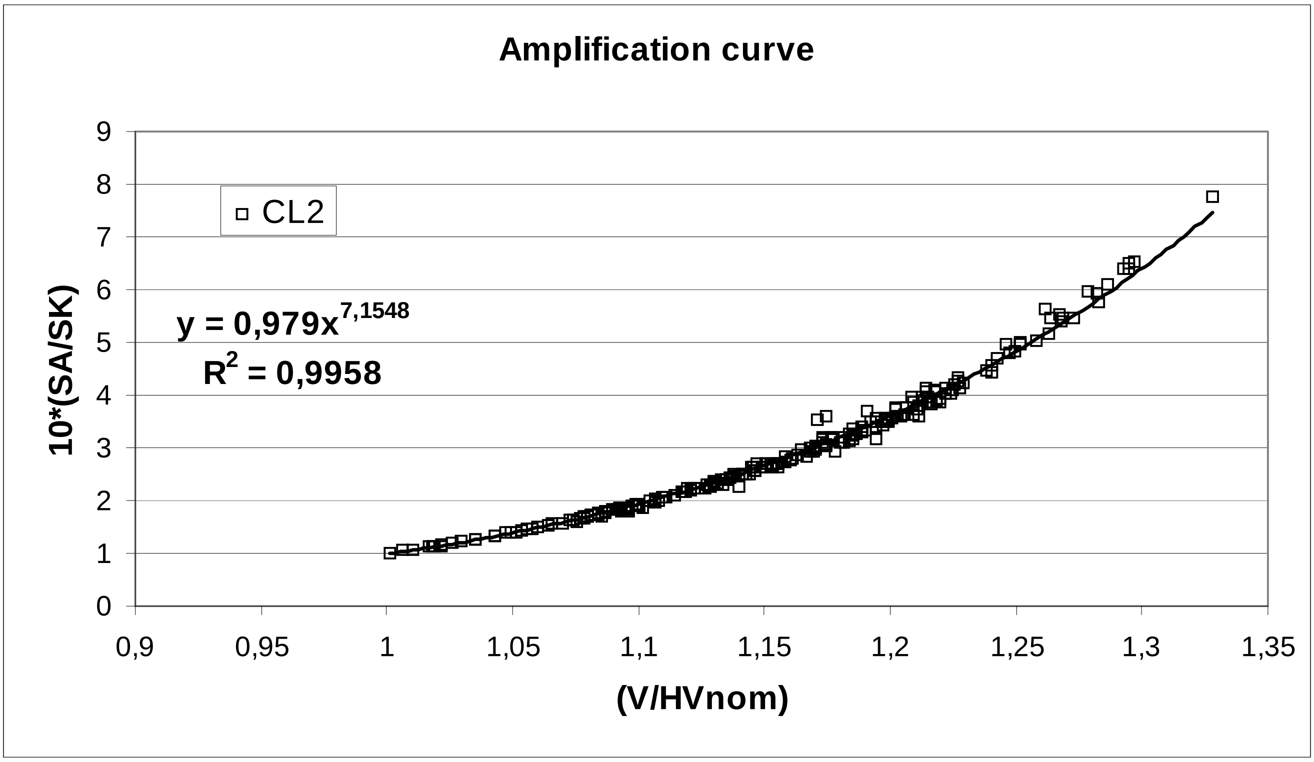

Figure (24) : Correlation 10 x S_A / S_K as a function of X = (V/ $HV_{Nom.}$) for batch #2

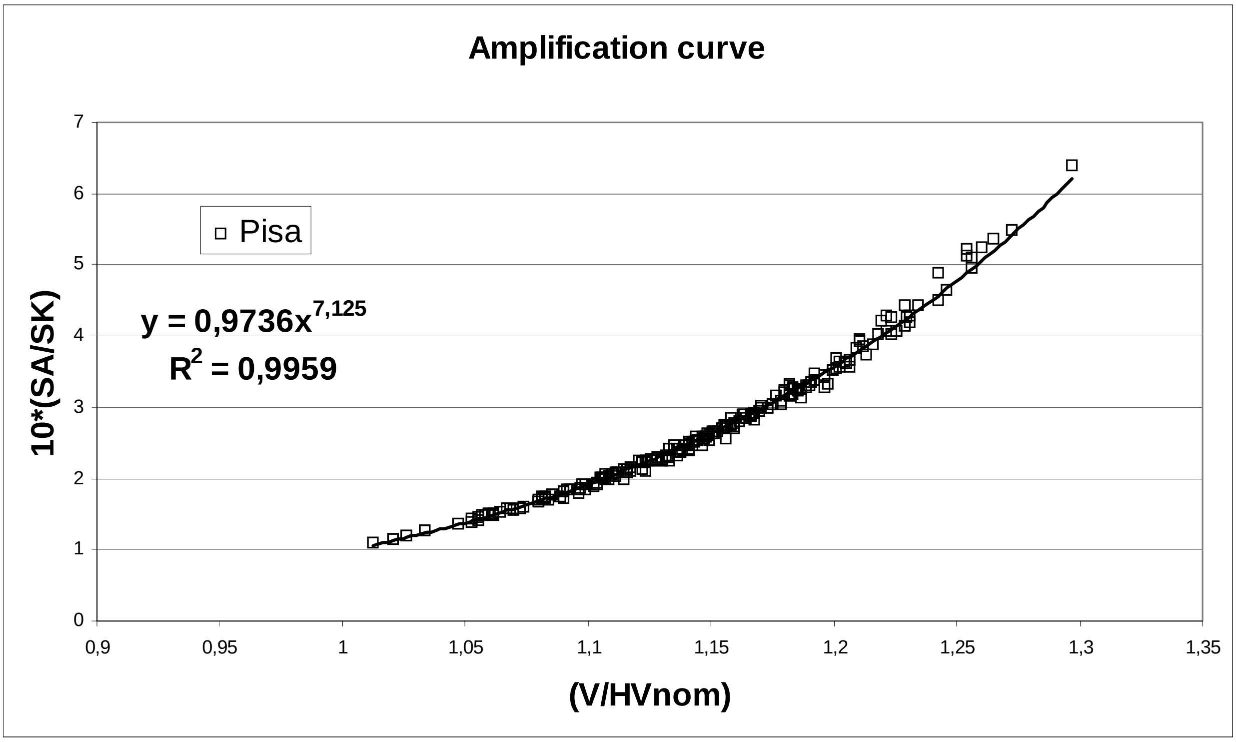

Figure (25) : Correlation 10 x S_A / S_K as a function of X = (V/ $HV_{Nom.}$) for batch #3 (Pisa)

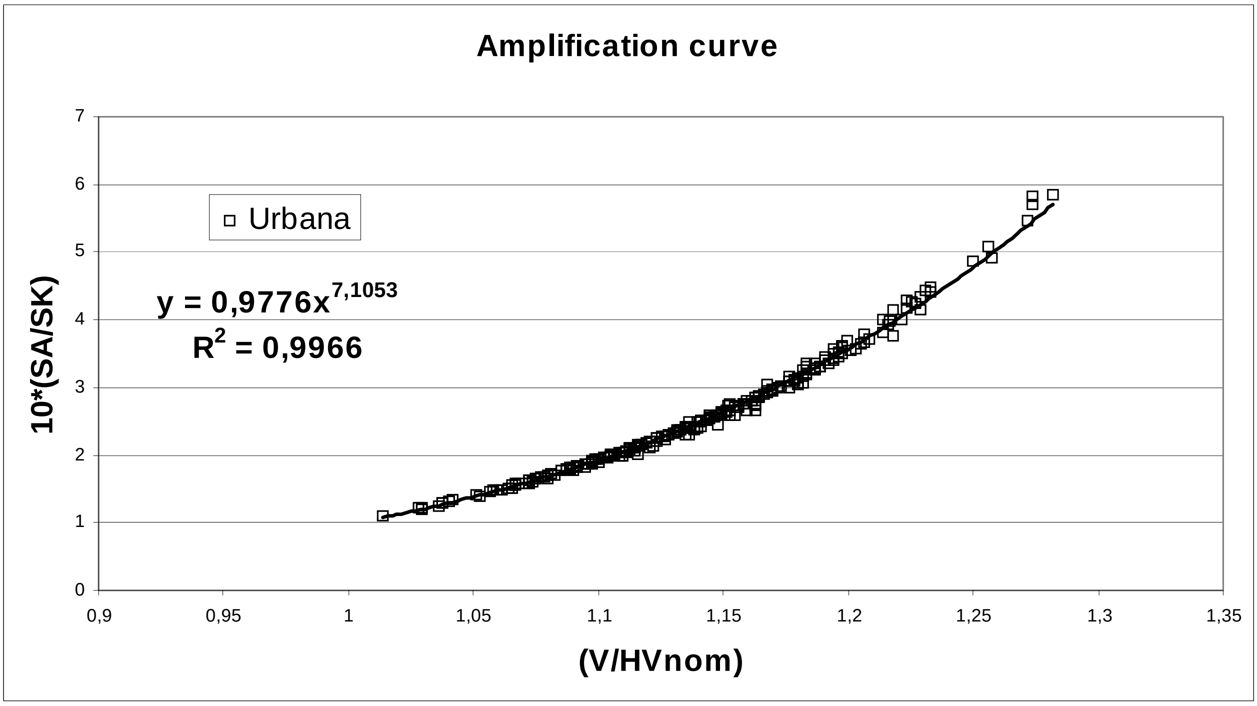

Figure (26) : Correlation 10 x S_A / S_K as a function of X = (V/ $HV_{Nom.}$) for batch #3 (Urbana)

Figure (27) shows the distribution of the measured β value for 3 of the 4 available batches (CL1, CL2 and Urbana).

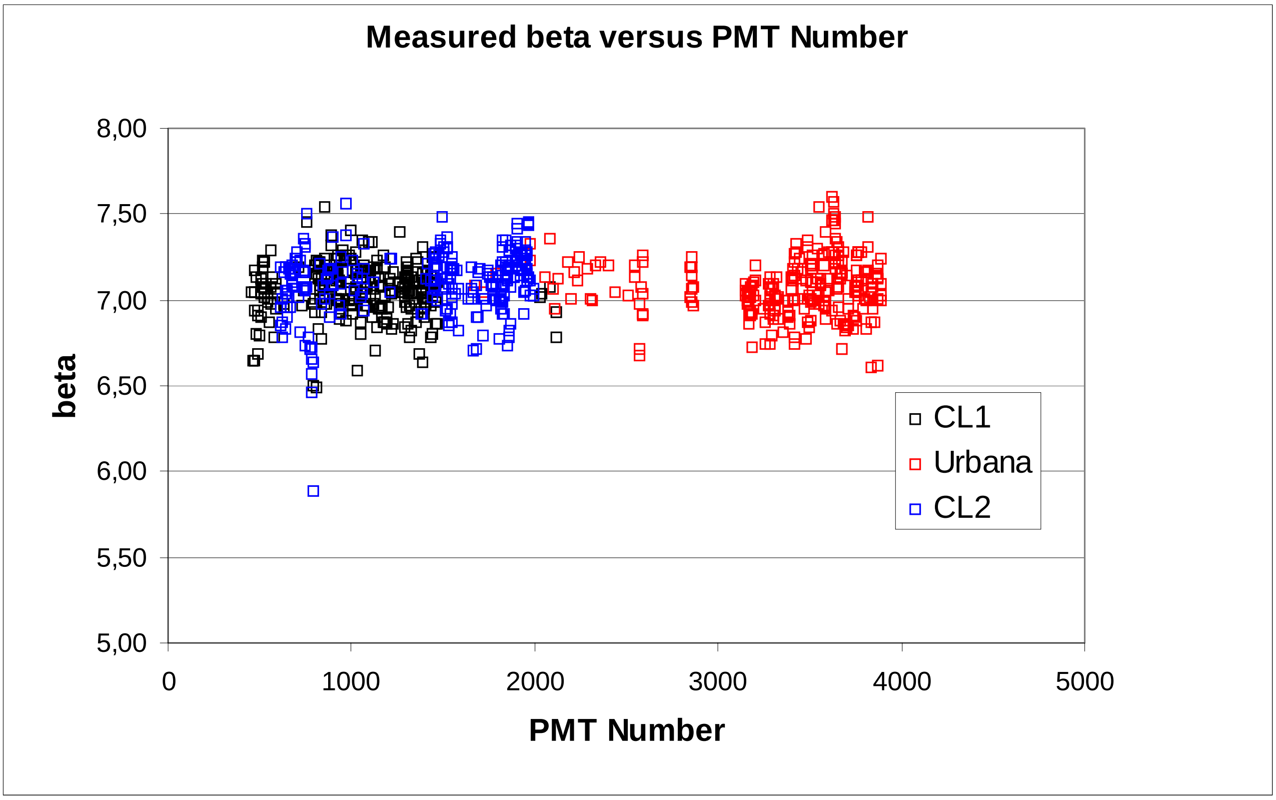

Figure (27) : Distribution of the measured β value for 3 of the 4 available batches (CL1, CL2 and Urbana).

3. Conclusions

Figure (28) shows the distribution of the nominal voltage as a function of the PMT serial number. This characteristic seems to be constant over all the 1000 first produced tubes.

Figure (29) shows the distribution of the nominal voltage for all the 1000 tubes. We got an averaged mean nominal value of 680 Volts with a dispersion of 33 Volts.

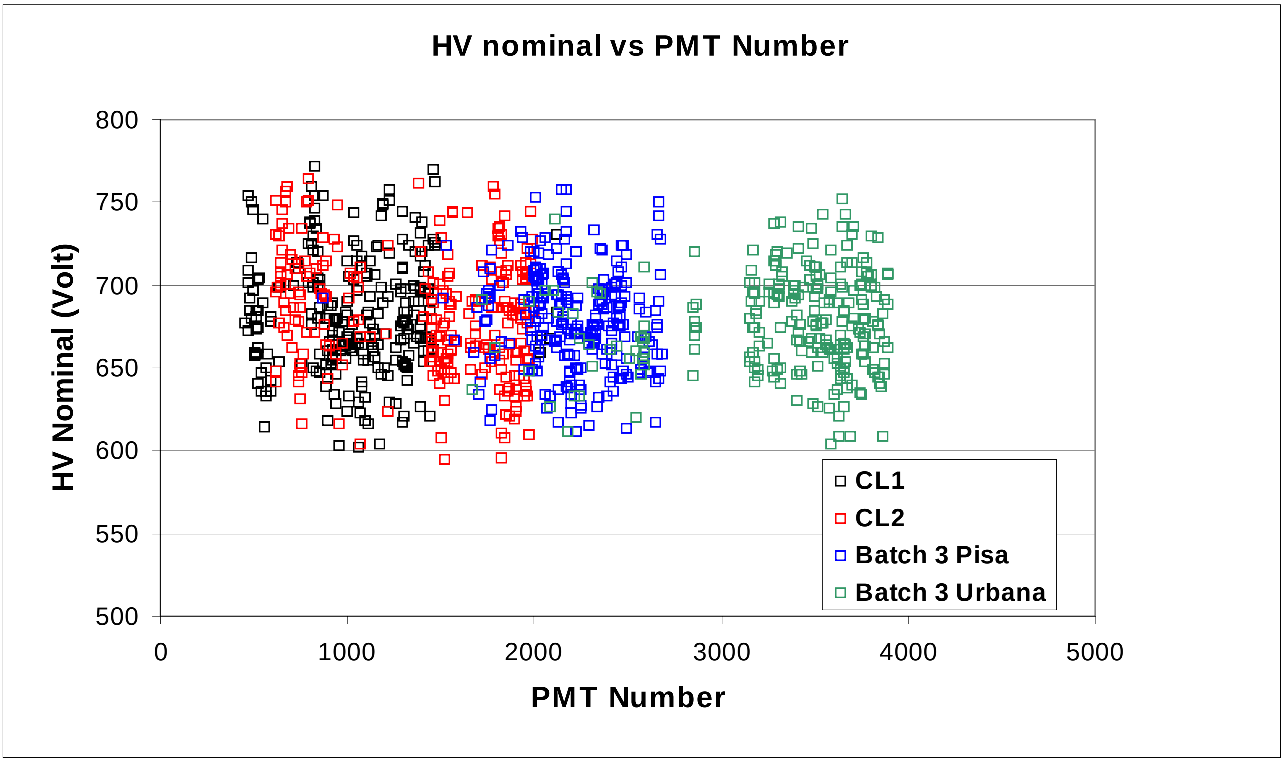

Figure (28) : Distribution of the nominal voltage as a function of the PMT serial number.

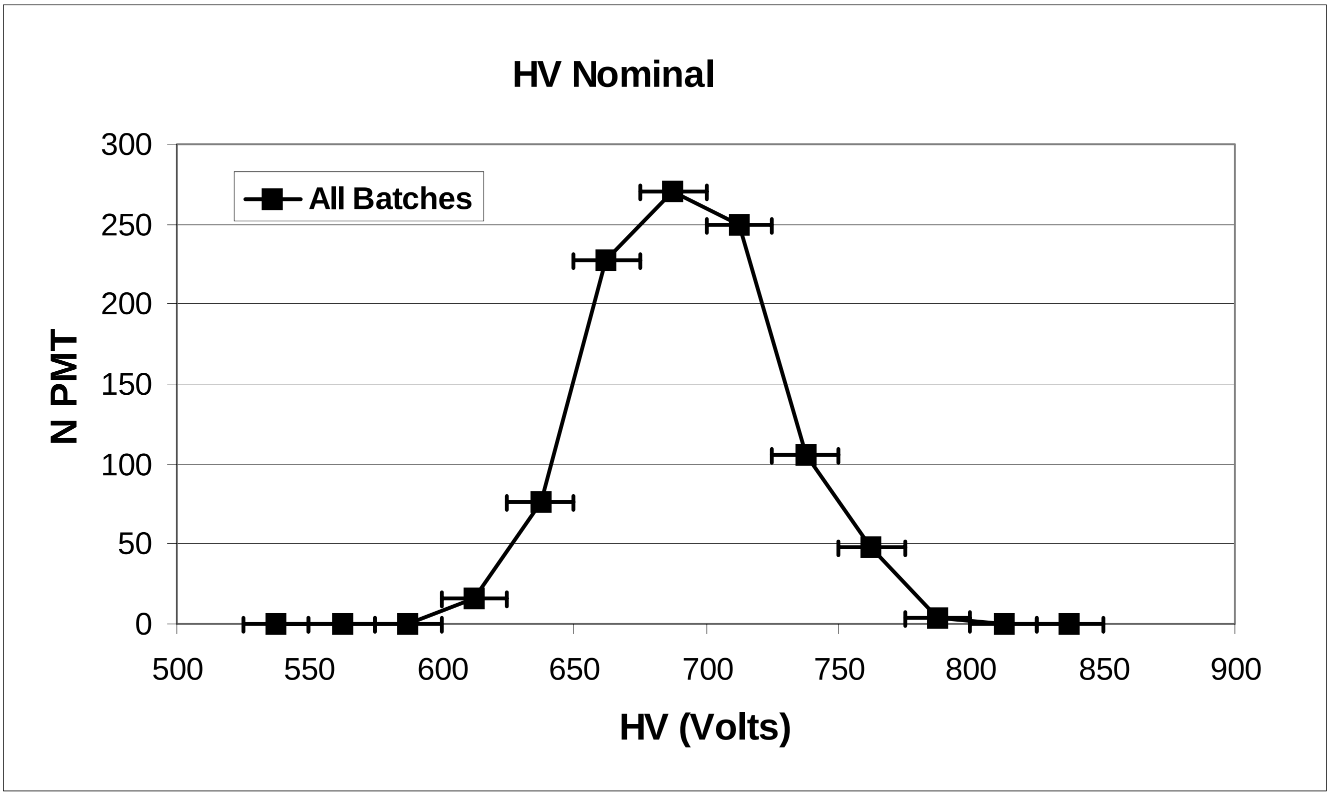

Figure (29) : Distribution of the nominal voltage for all the 1000 tubes

Figure (30) shows the distribution of the nominal voltage for the four sub-batches: CL#1, CL#2, Pisa and Urbana. We got the following averaged mean nominal values with dispersions :

- Batch #1 (CL1) ➔ $<HV_{Nom}>$ = 682 Volts and a dispersion of 35 Volts
- Batch #2 (CL2) ➔ $<HV_{Nom}>$ = 682 Volts and a dispersion of 36 Volts
- Batch #3 (Pisa) ➔ $<HV_{Nom}>$ = 678 Volts and a dispersion of 30 Volts
- Batch #3 (Urbana) ➔ $<HV_{Nom}>$ = 677 Volts and a dispersion of 33 Volts

Figure (31) shows the distribution of the β for 750 tubes. We got an averaged mean nominal value of 7,08 with a dispersion of 0,17.

- Batch #1 (CL1) ➔ $<\beta>$ = 7,05 and a dispersion of 0,16
- Batch #2 (CL2) ➔ $<\beta>$ = 7,10 and a dispersion of 0,19
- Batch #3 (Urbana) ➔ $<\beta>$ = 7,08 and a dispersion of 0,17

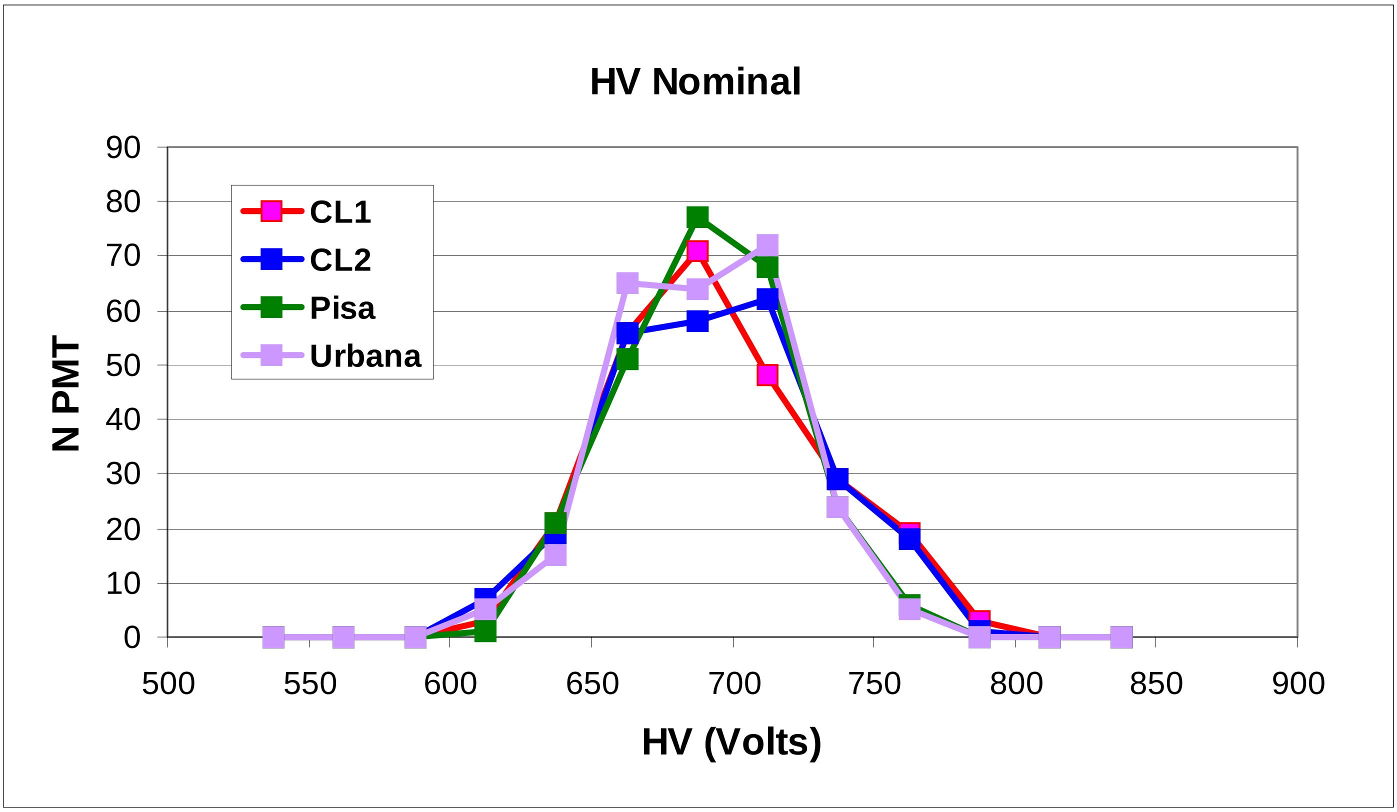

Figure (30) : Distribution of the nominal voltage for the four sub-batches: CL#1, CL#2, Pisa and Urbana

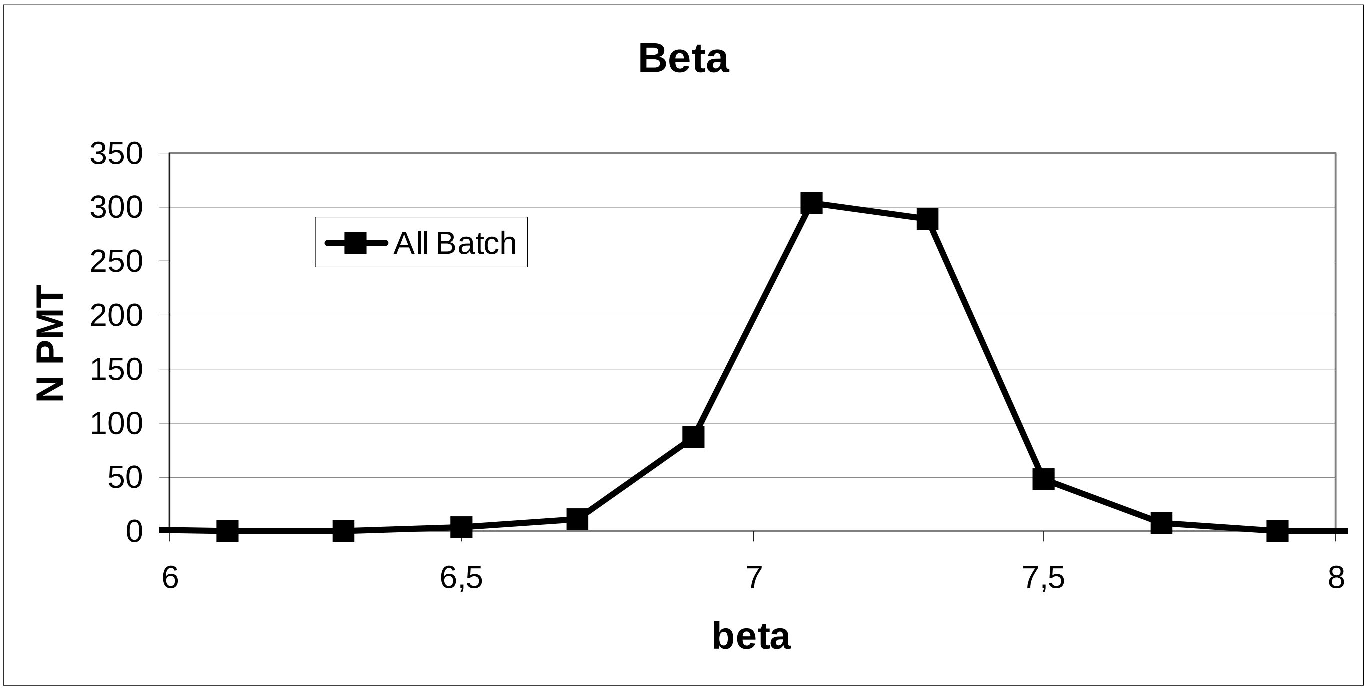

Figure (31) : Distribution of the β for 750 tubes. We got an averaged mean nominal value of 7,08 with a dispersion of 0,17

As a final conclusion, the production of the 1000 first tubes exhibits a good stability considering the current amplification characteristic. All the tubes are within the range [600-800] Volts with an averaged nominal voltage of 680 Volts.

The amplification curve could be fitted as a first approximation by the law $G = \alpha V^{\beta}$.

The β parameter is also rather constant over 750 tubes with an average of 7,08 and a dispersion of 0,17

Hamamatsu change the method to measure S_A for some tubes during production without any feedback as stated in the contract